Adaptation of Optimal Control Techniques for Path planning of Hyper-redundant manipulators in real-time

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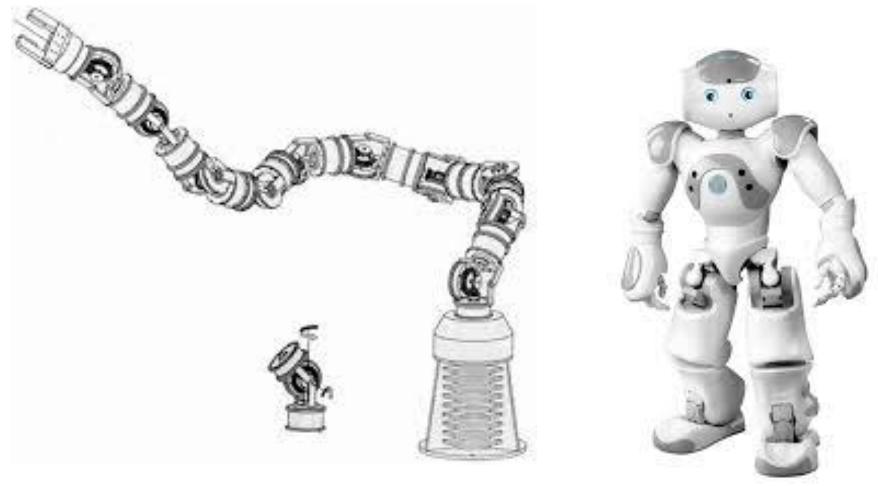
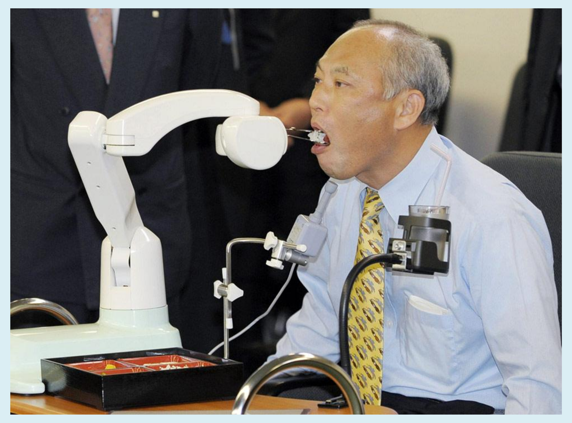


Motivation:

- Robots are required to perform complex tasks in cluttered environment autonomously.
- Human-Robot interaction is increasing for better co-existence, thereby elevating the safety factor to provide more trust.
- Assistive robots help humans with their activities in various environments.
- Dynamic environments require robots to react fast to avoid collision with obstacles.



Objective:

- To plan the motion of robotic manipulators in the most optimal manner.
- To perform path planning in real-time for such applications.
- To address the inapplicability of existing methods to hyper-redundant manipulator arms

Problem Statement:

The need for robotic arms to behave autonomously in human environments interacting with humans has increased many fold in the recent years. This requires the robotic system to sense and act independently. This research concentrates on one of the main aspect of such behavior: path planning. Not only the motion of the robotic arm is planned, but also in the most efficient and time optimal way to be able to react better and faster if needed. This is very critical from a human perspective to feel safer working in conjunction with robots.

Contributions:

- Provides an optimal/sub optimal path if one exists
- Applicable to real-time applications.
- Applicable to any kind of robotic manipulator with known kinematics.
- Path can be optimized for various parameters such as time, energy, shortest path, etc.
- Highly beneficial and practical for manipulators with high DOF's operating in cluttered spaces.

Previous Methods and its drawbacks:

- Dynamic Programming – Curse of Dimensionality.
- Potential fields – Local minima.
- Genetic Algorithms: Optimal but high computational time.
- Rapidly Exploring Random Trees – Not suitable for higher dimensions.
- Optimization techniques – Local minima, Boundary following techniques.

Future Work:

- Implement path planning to humanoids with two arms which looks into collision detection between the arms and the arms with the torso.
- Implement path planning to arms mounted on mobile platforms.

Method

Multi-pass Sequential Localized Search (MPSLS)

- Configuration Space discretized to create a roadmap where each grid point represents a collision free configuration of the arm.
- A cost-to-arrive function is used to find next optimal grid point in the roadmap, thereby obtaining an optimal path connecting the start and target configuration. $J = d_{\theta_{curr}-\theta_{target}} - d_{arm-obstacles}$.
- A Sequential Localized Search (SLS) is employed which only looks in the neighborhood of the current configurations to obtain the next optimal point which minimizes its distance to the target, until the target is reached.
- Collision detection is performed in the Cartesian space to candidates, in the order of their distance from the target. The candidate that passes is chosen as the next grid point.
- Three primitive shapes sphere, cylinder and plane are used to model obstacles and manipulator.
- Each pass of the SLS is performed in a sparsely discretized C-space giving rise to minimal number of way points. Multiple passes are performed taking the path from the previous pass until desired path discretization is obtained.
- Local minimas near obstacles are avoided using backtracking technique from the path obtained from the previous pass.

Time Saving Techniques

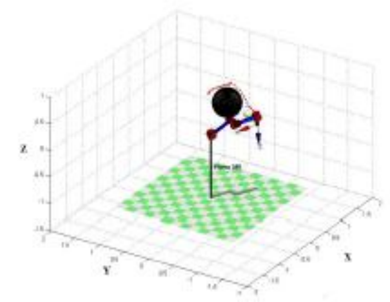
- A localized search is done using a set of random candidates from the available 3^m, neighbors, saving time exponentially for large DOF arms.
- Optimal path is obtained in multiple passes rather than in a single shot.
- Oriented bounding box between the start and target configurations is used to determine the closest obstacles for collision detection.
- Candidates are evaluated for the cost function before collision detection.

Simulation Results

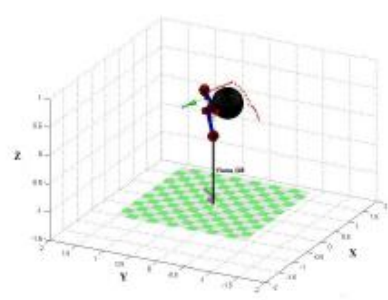
(i) PUMA-560

PUMA 560 Path planning statistics

ζ (m)	Without Obstacle					With Obstacle				
	N_c	c	t_s (s)	J_n^* (°)	J_n^* (m)	N_c	c	t_s (s)	J_n^* (°)	J_n^* (m)
0.03	47	6	2.07	171.22	3.126	74	7	2.83	628.6	4.197
0.06	23	4	1.30	171.22	3.114	37	5	1.57	628.6	4.186
0.08	23	4	1.20	171.22	3.114	28	4	1.28	628.6	4.180
0.15	12	3	0.83	171.22	3.108	18	3	0.98	628.6	4.172
0.3	10	2	0.72	171.22	3.105	13	2	0.82	628.6	4.149



(a) Start configuration.



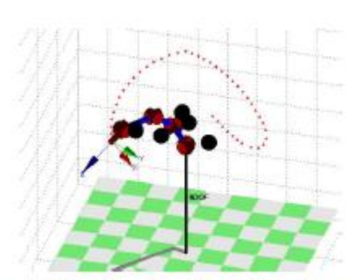
(b) Target configuration.

(ii) 9-DOF

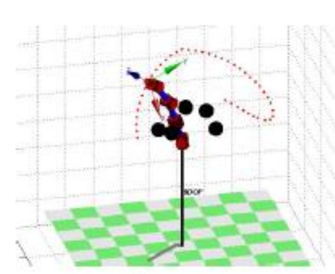
Repetitions = 5

Samples	ζ = 75mm				ζ = 125mm			
	t_s (s)	N_c	J_n^*(mm)	J_n^*(°)	t_s (s)	N_c	J_n^*(mm)	J_n^*(°)
50	10.12	61	7212.2	11361	6.14	35	6952.5	1136.1
100	10.45	53	6225.7	860.6	6.71	30	6215.3	860.6
250	11.85	44	5258.4	1117.4	6.85	25	5246.0	1117.4
500	17.87	36	3852.2	781.4	10.32	20	3837.0	781.4

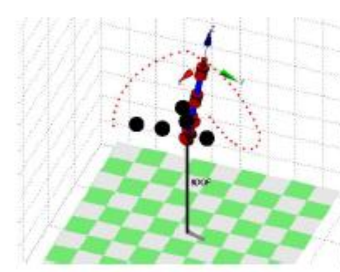
Obstacle	Location x (mm)	Location y (mm)	Location z (mm)	Radius (mm)
1	250	320	250	50
2	0	100	300	45
3	120	175	150	55
4	-200	175	150	52
5	-100	300	350	42
Ground Plane				
P1	700	700	-2	
P2	700	-700	-2	
P3	-700	-700	-2	
P4	-700	700	-2	



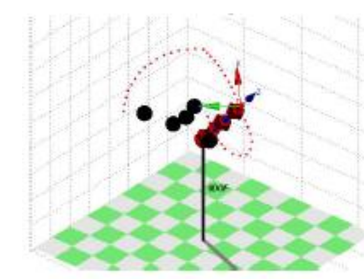
(a) Starting Configuration $P_{1,4}$



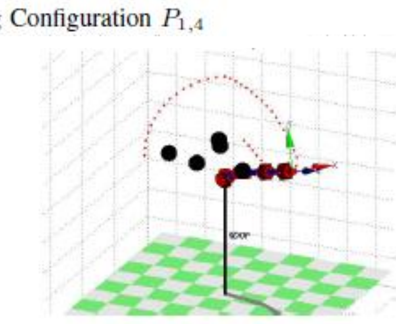
(b) $P_{10,4}$



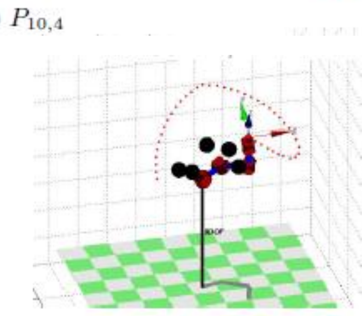
(c) $P_{20,4}$



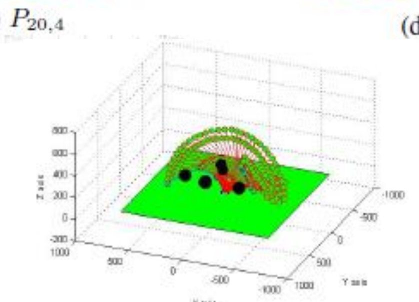
(d) $P_{28,4}$



(e) $P_{35,4}$



(f) End Configuration $P_{44,4}$



(g) MATLAB Output

Conclusions

Significance:

- Provides optimal path per the cost function.
- Can adapt to dynamic environments quickly.
- Convex hull can be dealt with easily.
- Navigation through tight spaces.
- Path planning of higher DOF arms in real-time.

Usefulness:

- Any kinematic structure can be accommodated in the path planning.
- Collision detection improves safety, thereby enabling human robot interface.
- Assistive robots like humanoids can operate reliably in human environment.

Improvements:

- Customized cost function for better path generation.
- Memory and speed optimized algorithm.
- Efficient sensing for tracking dynamic obstacles.
- Path planning considering the dynamics of the manipulator.